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FIXED-INTERVAL MATCHING-TO-SAMPLE: INTERMATCHING TIME AND INTERMATCHING ERROR RUNS[1]

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Four pigeons were trained on a matching-to-sample task in which reinforcers followed either the first matching response (fixed interval) or the fifth matching response (tandem fixed-interval fixed-ratio) that occurred 80 seconds or longer after the last reinforcement. Relative frequency distributions of the matching-to-sample responses that concluded intermatching times and runs of mismatches (intermatching error runs) were computed for the final matching responses directly followed by grain access and also for the three matching responses immediately preceding the final match. Comparison of these two distributions showed that the fixed-interval schedule arranged for the preferential reinforcement of matches concluding relatively extended intermatching times and runs of mismatches. Differences in matching accuracy and rate during the fixed interval, compared to the tandem fixed-interval fixed-ratio, suggested that reinforcers following matches concluding various intermatching times and runs of mismatches influenced the rate and accuracy of the last few matches before grain access, but did not control rate and accuracy throughout the entire fixed-interval period.

Key words: intermatching time, intermatching error runs, matching-to-sample, interresponse time, matching accuracy, matching rate, fixed-interval schedule, ratio schedule, pigeons

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Schedules of reinforcement are generally considered to have significant, orderly, and reproducible effects on behavior. Our understanding of how reinforcement schedules influence behavior can be advanced if the critical properties of various schedules necessary for their effectiveness can be identified.

A fixed-interval (FI) schedule prescribes a minimum fixed period of time between reinforced responses. One property of FI schedules is that, if there is some variation in the rate of responding for the last few responses in the terminal part of the interval, reinforcers are more likely to follow responses relatively far apart in time than responses close together in time (Dews, 1969; Skinner, 1938). This property of FI schedules tends to engender a moderate rate of responding (Killeen, 1969). Generally, the differential reinforcement of responses according to the time since the prior response is considered to be an important aspect of reinforcement schedules which influences response rate (Anger, 1956; Blough, 1966; Catania and Reynolds, 1968; Kuch and Platt, 1976; Morse, 1966; Shimp, 1967, 1973).

The schedule of reinforcement influences not only the rate at which responses occur, but also the accuracy of the more complex response, matching-to-sample. A typical matching-to-sample procedure is to present one stimulus (sample) followed by two or more comparison stimuli, one of which is similar to the sample. A response to the comparison stimulus similar to the sample is recorded as a match; a response to the nonmatching comparison stimulus is recorded as a mismatch or error. The schedule of reinforcement affects both the rate of matching and the relative proportion of matches to mismatches (accuracy) (Boren and Gollub, 1972; Clark and Sherman, 1970; Ferster, 1960; Nevin, Cumming, and Berryman, 1963). Ferster (1960) found that under multiple fixed-interval fixed-ratio schedules of matching-to-sample, the amount of mismatching was generally higher during the FI component than the fixed-ratio.

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However, the particular aspects of an FI schedule that influenced matching accuracy were not identified.

When the operant response is a single key peck instead of the discriminated operant response of matching-to-sample, FI schedules arrange that reinforcement is more probable following responses that are relatively distant in time from the prior response than responses occurring close together in time (Dews, 1969). Extending this aspect of FI schedules to matching-to-sample implies that matches separated from the prior match by relatively long time periods will be preferentially reinforced. This interpretation suggests that FI schedules will control moderate rates of matching-to-sample if the preferential reinforcement of matches concluding relatively extended intermatching times is an important aspect of FI schedules in determining matching rate.

Preferential reinforcement of matches concluding relatively extended intermatching times is also an aspect of FI schedules that could control matching-to-sample accuracy. Although only matches are immediately followed by reinforcers, the effect of reinforcement is not limited to the response immediately preceding the reinforcer, but also extends to behaviors preceding the final response, so that these behaviors also become more frequent (Catania, 1971). Under the FI schedule, if mismatches that occur between matches increase the time between matches, then reinforcers would be more likely to follow matches concluding runs of mismatches than matches preceded directly by matches. Fixed-interval schedules should favor moderate matching accuracy if the preferential reinforcement of matches terminating relatively long runs of mismatches is important in determining matching-to-sample accuracy on FI schedules.

One purpose of the present experiment was to verify empirically that FI schedules of matching-to-sample arrange for the preferential reinforcement of matches concluding relatively extended times since the previous match, or relatively long runs of mismatches. A second purpose was to assess the contributions of this aspect of the FI reinforcement contingency to matching rate and accuracy by adding a ratio requirement to the fixed-interval contingency.

METHOD

Subjects

Four female Silver King pigeons were maintained at approximately 80% of their free-feeding body weights. The pigeons had previously served in an experiment on the discrimination of IRT duration.

Apparatus

An experimental chamber measuring 30.4 cm by 33.4 cm by 28.0 cm in the subject's compartment was equipped with three translucent response keys arranged horizontally and spaced 9.5 cm apart, center to center, and 21 cm above the floor of the chamber. A minimum force of approximately 0.15 N was required to operate each response key. Pecks of sufficient force under appropriate stimulus conditions operated a relay mounted on the aluminum panel separating the subject's compartment from the stimulus and grain delivery devices, and produced a feedback click. Response keys were transilluminated by red or green light from Grason-Stadler inline projectors. No houselights were present. The chamber was equipped with a ventilation fan, and continuous white noise was present outside the chamber.

In an adjoining room, the scheduling of experimental events was accomplished with electromechanical apparatus. During the final sessions of each condition a Sodeco print-out counter was used to record sequentially the times between matches or the number of errors between matches.

Procedure

Experimental sessions were conducted daily and terminated after 60, 3-sec presentations of mixed grain. All four pigeons were exposed to a zero-delay matching-to-sample task. The center key was transilluminated with either red or green light (sample) while the two side keys were dark. A peck on the center key darkened it and transilluminated the two side keys, one of which was transilluminated with red light, the other with green. A peck on the side key of the same color as the sample was recorded as a match; a peck on the alternative color was recorded as a mismatch or an error. The color of the sample and the position of the colors on the side keys varied irregularly, but appeared with equal frequency at each position. Each sample was independent of whether the previous side-key response was a match or mismatch (noncorrection procedure).

Matching-to-sample responses were reinforced according to two different schedules. During Condition 1, which was in effect for 75 sessions for Pigeons 79, 64, and 69, and 76 sessions for Pigeon 74, and Condition 3, which was in effect for 45 sessions for Pigeon 69, and 46 sessions for the remaining three pigeons, matching-to-sample responses were reinforced according to an FI 80-sec schedule. The first matching response occurring 80 sec or more since the last reinforcement produced a 3-sec access to mixed grain. Matches and mismatches during the fixed-interval were immediately followed by the next sample. There were no consequences, such as magazine light flashes after matches, or blackouts after mismatches. During Condition 2, which was in effect for 48 sessions for Pigeons 74 and 64, and 49 sessions for Pigeons 79 and 69, matching-to-sample responses were reinforced on a tandem FI 80-sec FR 4 schedule. During the tandem FI 80-sec FR 4 condition, reinforcers followed the fifth match that occurred 80 sec or more after the previous reinforcement. Mismatches were ineffective with respect to the requirement of four matches under the FR 4.

RESULTS

Relative Frequency Distributions

Relative frequency distributions of intermatching time for each experimental condition and for each pigeon are shown in Figure 1. The data in Figure 1 were recorded during two complete sessions of each experimental condition and are therefore based on 120 fixed-interval periods for each condition. Because apparatus limitations precluded the simultaneous recording of sequential intermatching times and sequential intermatching error runs, the six sessions during which intermatching times were sequentially recorded were the last two sessions of the tandem FI FR schedule and Sessions 66 and 67 of the original FI for all pigeons except Pigeon 74, for which the data were recorded in Sessions 67 and 68. During the redetermination of the FI schedule sequential intermatching times were recorded during Sessions 36 and 37 for all pigeons except Pigeon 79, for which the data were recorded during Sessions 35 and 36. None of the data in Figure 1 was recorded until no systematic changes in responding were observed for a minimum of five consecutive sessions.

Figure 1 shows the relative frequency of matches terminating in each 2-sec intermatching time class interval for the match immediately followed by grain (N) and the three matches immediately preceding the N matches (N-1, N-2, N-3). The distributions for the N-1, N-2, and N-3 matches were combined and averaged to increase sample size, as they showed no systematic differences. The numbers in Figure 1 indicate the total number of matches from which the relative frequency distributions were constructed. The means for each class interval are connected and the two session ranges are shown.

Figure 1 shows several results. First, the FI schedules arranged for reinforcers preferentially to follow matching responses concluding intermatching times longer than 4 sec. The preferential reinforcement was shown by the difference between the relative frequency with which a given intermatching time occurred in the N distribution compared to the N-1, N-2, N-3 distribution. For every subject under the FI conditions, the mean relative frequency of the N-1, N-2, N-3 distribution was greater than the mean of the N distribution for the earliest, 0 to 2 sec, intermatching time class interval. For most intermatching times longer than 4 sec, the mean values for the N distribution were equal to or greater than the values for the N-1, N-2, N-3 distribution under the FI schedules.

Second, the preferential reinforcement of extended intermatching times was eliminated under the tandem FI FR condition. The middle panels of Figure 1 show that the relative frequencies of intermatching times based on the N distribution were similar to the relative frequencies based on the N-1, N-2, N-3 distribution.

Figure 2 shows relative frequency distributions of intermatching error runs for each experimental condition for each pigeon. The means for each error run length are connected and two session ranges are indicated. The numbers indicate the total number of matches on which the frequency distributions were based. The data shown in Figure 2 were recorded during the last two sessions of the original FI condition and the redetermined

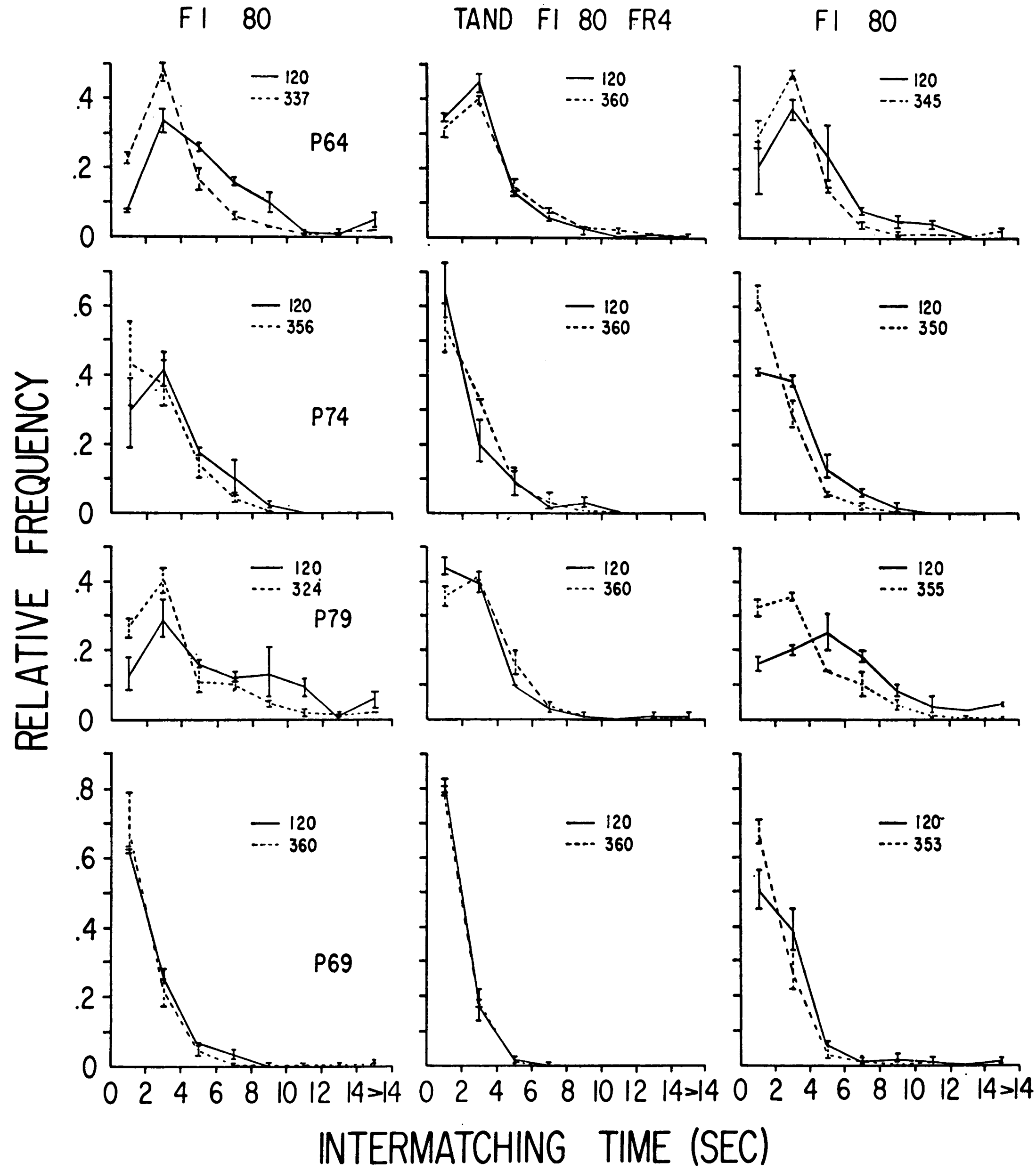

Fig. 1. Relative frequency distributions of matching-to-sample responses concluding various intermatching times under FI and tandem FI FR schedules. The solid line represents the final matching response immediately followed by grain and the dashed line represents the three matches preceding the final match. The means are connected and two session ranges are shown. The numbers indicate the total number of matches used to derive each distributions.

FI condition, and in Sessions 47 and 48 of the tandem FI FR for Pigeons 64 and 74 and Sessions 48 and 49 for Pigeons 69 and 79. These data show the relative frequency with which matches concluded runs of mismatches of various lengths for both the N distribution and the N-1, N-2, N-3 distribution under the FI and tandem FI FR conditions.

Comparison of the difference between the relative frequencies of intermatching error runs based on the N distribution to the relative frequencies based on the N-1, N-2, N-3

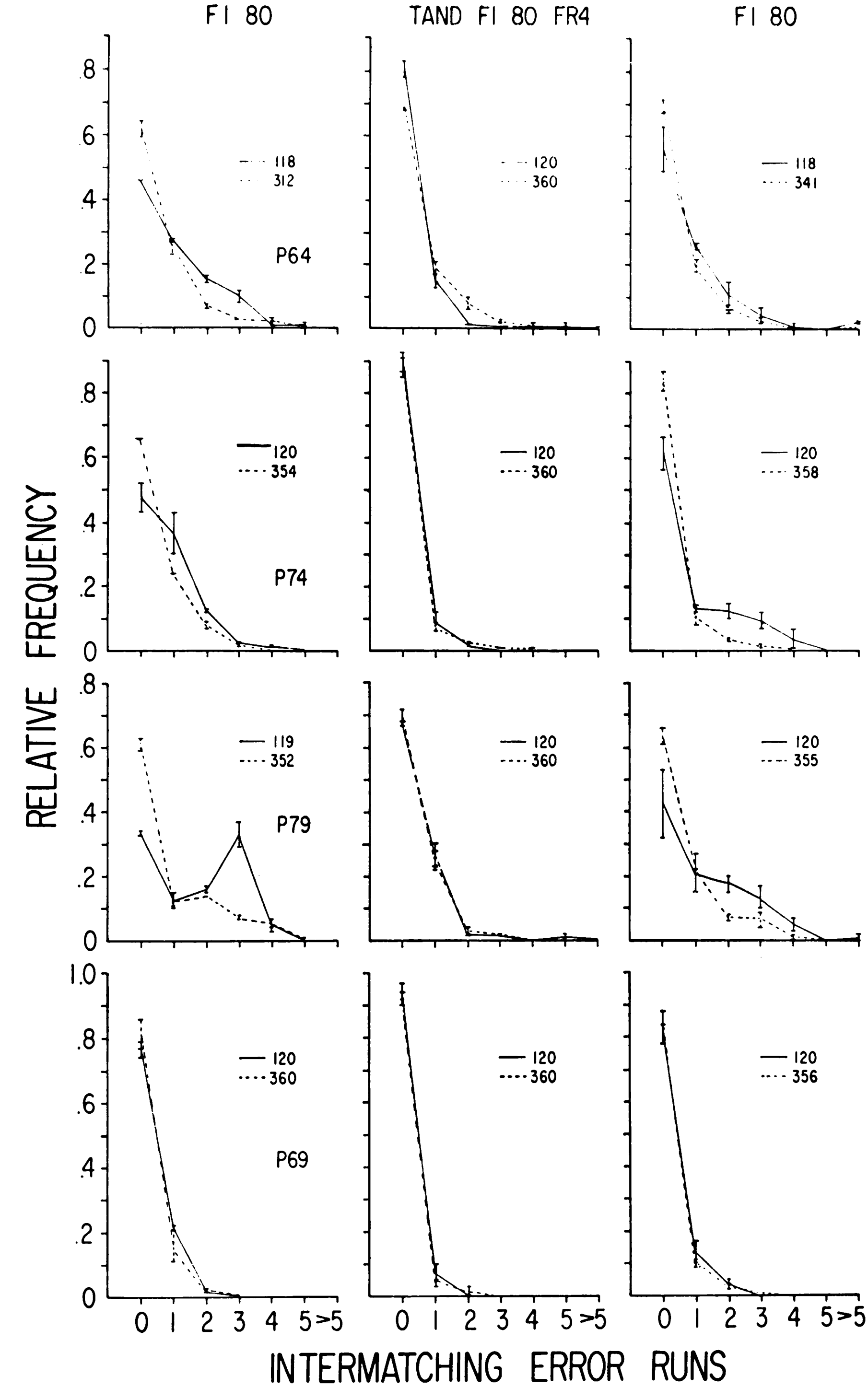

Fig. 2. Relative frequency distributions of matching-to-sample responses concluding various runs of mismatches under FI and tandem FI FR schedules. The solid line represents the final matching response immediately followed by grain and the dashed line represents the three matches preceding the final match. Numbers indicate the total number of matches used to derive the distributions.

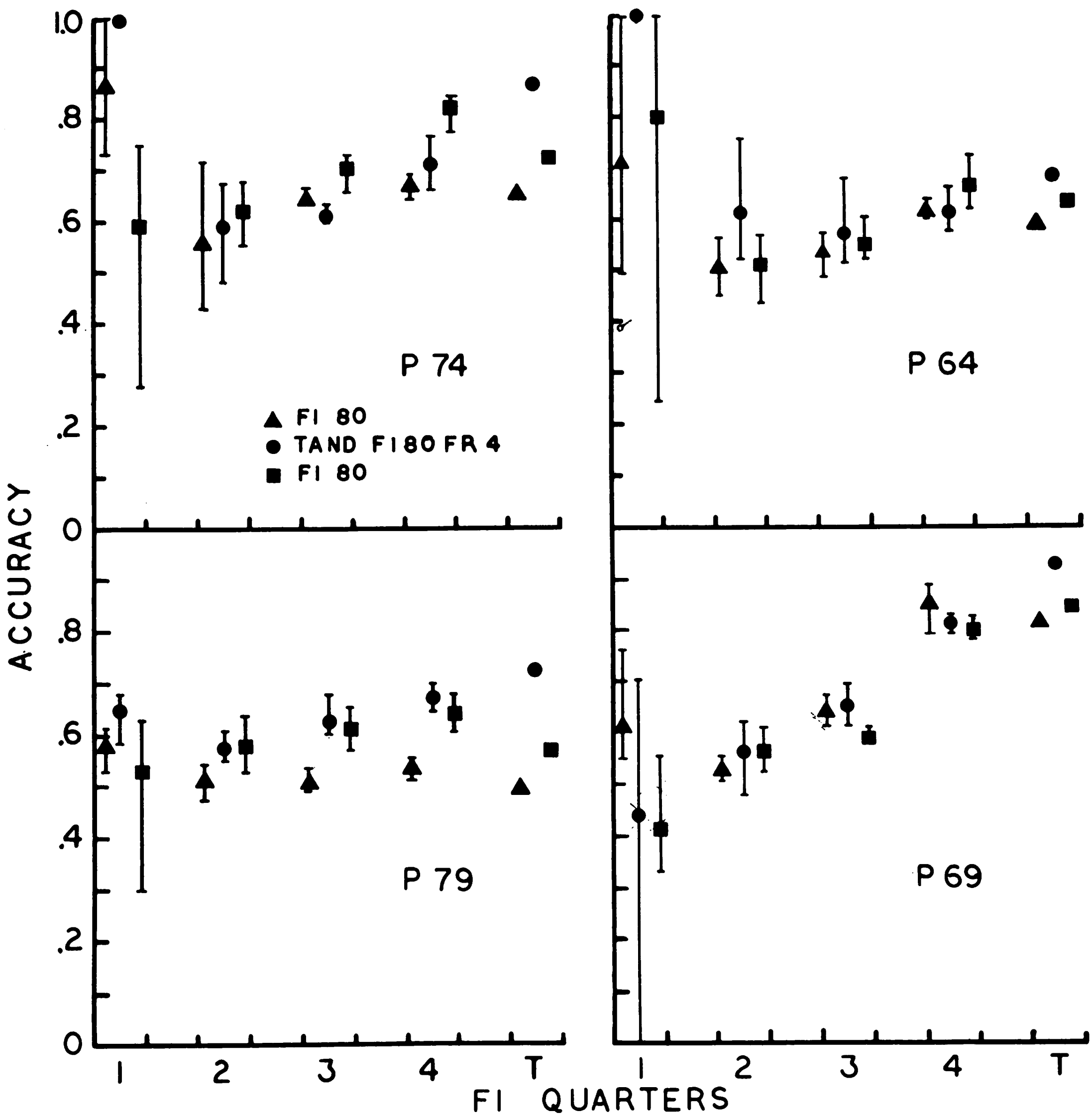

Fig. 3. Accuracy (matches divided by matches plus mismatches) and ranges over consecutive quarters of the FI and FI component of the tandem FI FR schedules. The terminal (T) period represents accuracy for the last few matches before reinforcement (see text). Data are means of the last five sessions under each schedule.

distribution under the FI conditions showed that the mean frequency with which error runs of zero length were followed by grain was less than the mean frequency with which such error runs occurred in the N-1, N-2, N-3 distribution. However, for matches terminating those error runs of length one or more, the mean relative frequency of the N distribution was usually greater than the mean relative frequency of the N-1, N-2, N-3 distribution under the fixed-interval conditions.

Accuracy and Rate

The effect of the added ratio contingency on matching accuracy is shown in Figure 3. Figure 3 shows the mean accuracy (matches divided by matches plus mismatches) and ranges based on the last five sessions of each experimental condition over consecutive quarters of the FI and FI component of the tandem FI FR. Instances where neither matches nor mismatches occurred in the first quarter of the FI were disregarded in computing accuracy

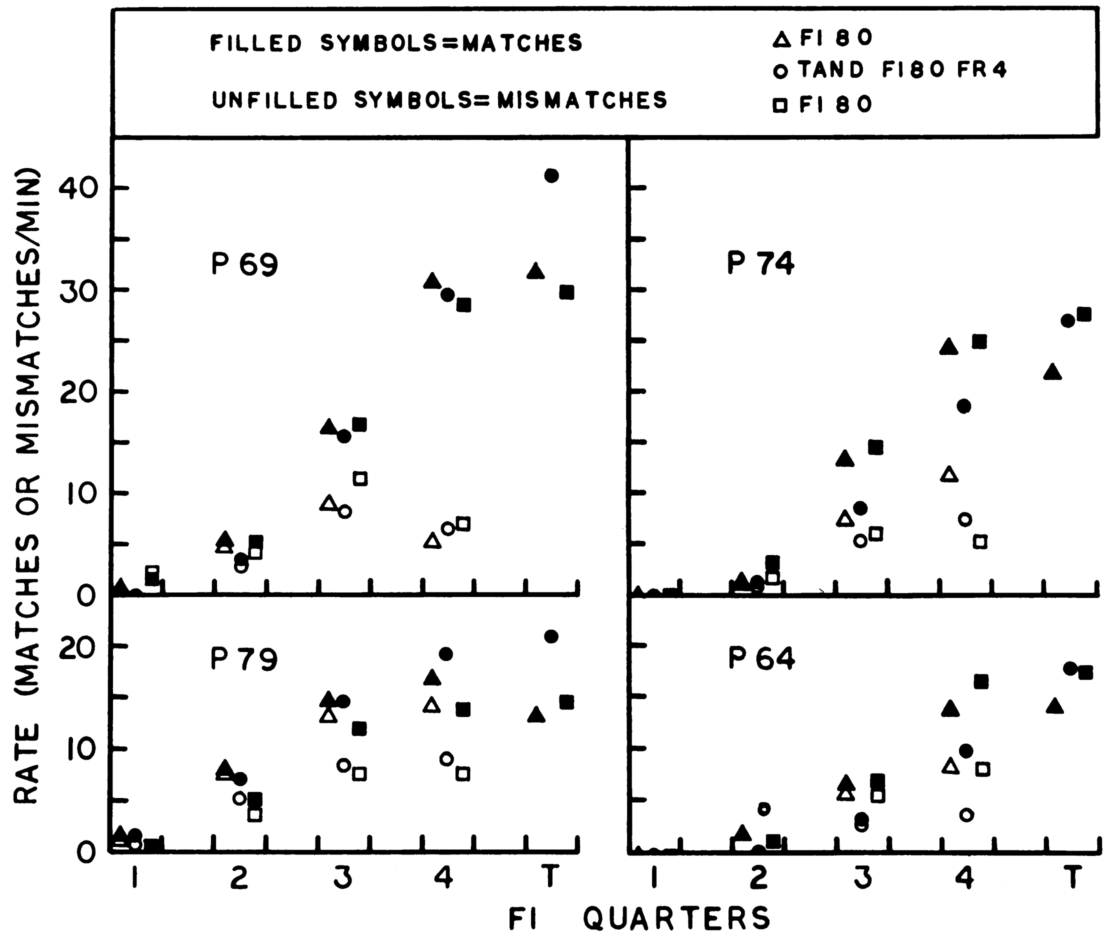

Fig. 4. Matching and mismatching rate over consecutive quarters of the FI and the FI component of the FI FR. Filled symbols are matches, unfilled symbols mismatches. The terminal (T) period shows matching rate for the last few matches before reinforcement (see text). Data are means of the last five sessions under each schedule.

in quarter one. Generally, accuracy was variable during the first quarter of the FI. Within a condition, accuracy tended to increase from the second to the fourth quarter of the 80-sec interval. The circles in Figure 3 represent the tandem FI FR condition and show that the addition of the ratio contingency resulted in no obvious systematic change in accuracy over the four FI quarters, compared to accuracy under the FI schedule alone.

Figure 3 also shows terminal (T) accuracy based on the matches and mismatches that occurred after the N-4 match. The terminal accuracy was computed from the relative frequency intermatching error-run distributions shown in Figure 2 by multiplying the total number of N, N-1, N-2, and N-3 matches terminating each error-run length by the intermatching error-run length and summing across intermatching error-run lengths to yield total mismatches that occurred after the N-4 match of each interval. The total number of matches in the N, N-1, N-2, N-3 distributions was divided by the total matches plus total mismatches to yield terminal accuracy. Figure 3 shows that the addition of the ratio contingency increased terminal accuracy of matching-to-sample for each subject. The redetermination of the FI condition lowered terminal accuracy for each subject.

The effect of the added ratio contingency on matching and mismatching rate is shown in Figure 4. Figure 4 shows the mean matching (filled symbols) and mismatching (unfilled symbols) rate for the last five sessions of each condition over consecutive quarters of the FI.

On each schedule, matching rate typically increased over consecutive quarters of the FI. Mismatching rate was lower than matching rate in nearly all FI quarters and generally increased over quarters or reached a maximum in quarter three and then decreased slightly in quarter four. The addition of the ratio contingency (circles in Figure 4) produced no obvious systematic change in the rate of matching or mismatching, compared to rate on the FI alone.

Figure 4 also shows terminal (T) matching rate derived from data used to compute the relative frequency distributions of intermatching times shown in Figure 1. To calculate terminal matching rate, the number of matches in each intermatching time class interval was multiplied by the midpoint of each band and summed across intervals to estimate total time from the N-4 match to reinforcement. Total matches comprising the N, N-1, N-2, N-3 distribution were divided by the estimated total time to yield terminal matching rate for each condition. Figure 4 shows that addition of the ratio contingency was accompanied by an increase in terminal matching rate for each subject above the rate during the terminal portion of the initial FI condition. The redetermination of the FI condition following the tandem FI FR lowered the terminal matching rate below the tandem FI FR condition for two of the four subjects. Sequential intermatching times and intermatching error runs were recorded during separate sessions, so that calculation of a terminal mismatching rate was not possible.

In summary, Figures 3 and 4 show that the addition of the ratio contingency was accompanied by an increase in both matching rate and matching accuracy based on the last few matching-to-sample responses before reinforcement, but had no obvious effect on accuracy or rate at earlier portions of the FI.

DISCUSSION

The present results indicate that the concepts derived from the study of interresponse time (IRT) may be extended to intermatching time. Dews (1969) found that when the response studied was a single key peck, FI schedules arranged for the preferential reinforcement of responses terminating relatively extended IRTs. The present study showed that when the response studied is matching-to-sample, FI schedules arranged for the preferential reinforcement of matches terminating relatively extended intermatching times. This preferential reinforcement was shown in both Dews' (1969) experiment and the present study by comparing the intermatching time (or IRT) of the final response producing food to intermatching time (or IRT) distributions of responses preceding the final response.

A given intermatching time or IRT should be followed by reinforcers in proportion to the time occupied by the intermatching time in the terminal portion of an FI (*cf.* Dews, 1969). That is, a 4-sec intermatching time that occurred half as frequently as a 2-sec intermatching time should yield the same number of reinforcers, because two 2-sec intermatching times and one 4-sec intermatching time occupy equal periods of time. In this sense, longer intermatching times were preferentially reinforced. Brief intermatching times (shorter than 2 sec) were underrepresented in the distribution, based on the final match, compared to distributions based on preceding matches; longer intermatching times were generally overrepresented.

An interesting aspect of studying matching-to-sample on FI schedules was the finding that matches concluding relatively long runs of mismatches were relatively more likely to be followed by reinforcers than matches not separated by mismatches. The simplest interpretation of this result is that mismatching increased the time between matches, and hence increased the likelihood that the FI concluded and the next match produced a reinforcer. This may be an important property of FI schedules of matching-to-sample and may partially account for the finding reported by Ferster (1960) that mismatching was greater during the FI component of a multiple FI FR schedule than during the FR component.

The preferential reinforcement of matches concluding relatively long intermatching times and intermatching error runs should always be observed on interval schedules because, by the definition of interval schedules, the timing of the interval is independent of responding. Hence, pauses between matches must increase the likelihood that the interval has concluded and the next match will be reinforced. The question remains as to the importance of this property of FI schedules in controlling matching-to-sample rate and accuracy.

Investigation of this question can proceed if the preferential reinforcement of longer intermatching times and error runs is eliminated without significantly changing other properties of the FI. The addition of a tandem ratio requirement eliminates preferential reinforcement of longer intermatching times and error runs because reinforcement is based on the number of matches after the interval has concluded; the time between these matches does not influence the probability of reinforcement. When the tandem ratio requirement was added to the FI, no reliable changes in matching-to-sample rate or accuracy over all four quarters of the 80-sec period were observed. This indicated that the overall matching-to-sample rate and accuracy on an FI-80 sec schedule were not controlled by the preferential reinforcement of relatively longer intermatching times. However, the added ratio requirement did influence the rate and accuracy of the last few matches before reinforcement. Based on the last few matching-to-sample responses before reinforcement, the relative frequency of intermatching times in the earliest class interval recorded (0 to 2 sec) usually was greater under the tandem FI FR than the FI. Also, the relative frequency of error-run lengths of zero was greater under the tandem FI FR than the FI. The matching rate and accuracy, as shown by the T-period, for the last few matches before reinforcement were higher under the tandem FI FR than the FI alone.

This study represents an initial attempt to identify properties of FI schedules that control matching-to-sample accuracy and rate. Additional experimentation is required. It would extend our understanding of how reinforcement schedules affect more complex behaviors if the time and numerical distributions of matches and mismatches occurring under differential-reinforcement-of-low-rate schedules of matching-to-sample were known. It would also be interesting to examine the relationships between reinforced intermatching times and intermatching error runs on variable-interval schedules of reinforcement, and emitted intermatching times and accuracy in a manner similar to the experiment on interresponse times on variable-interval schedules conducted by Anger, (1956).

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